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PROBLEMS OF METROLOGICAL VERIFICATION OF SOFTWARE FOR MODERN MEASURING INSTRUMENTS

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ABSTRACT

In this article the considerations concerning the necessity of metrological verification of measuring instruments software are presented. The purpose of work is an acquaintance of the scientific world with the main tendencies in the development of metrology of modern measuring instruments and justification of the need for metrological verification of measuring instruments software.

Index Terms - metrological verification, software, measuring instrument, cyber-physical system

1. INTRODUCTION

During the last 5 years, the department of information and measurement technology, National University "Lviv Polytechnic", team of scientists is engaged in problems of the metrological verification (MV) of modern measuring instruments (MI) especially of their software. The studied methods and have repeatedly been presented at scientific and methodological seminars, and conferences. This issue has always evoked the lively discussion and often misunderstanding and rejection of the proposed concepts of MV of MI software.

Why is there such a situation? And why, in our opinion, should be given essential attention to abovementioned problem.

First, this work is on the border between metrology and digital (microcontroller and microprocessor) technology, which in recent decades has rapidly burst into the measuring equipment [1-4]. Almost every modern MI is not projected without a microcontroller. In many cases, a personal computer becomes a part of MI (LabVIEW, etc.). In this case, the main processing of the measurement results is fulfilled on a PC.

Second, no one ever metrological principles have been applied to digital equipment and software, since basically necessity of it is absent. Nowadays, taking into account the wide integration of microprocessors with software to MI, which are characterized by the metrological characteristics, the logical question arises: how to take into account software inexactness and how it should pass MV of measuring methods to obtain valid results of verification?

Third, software vendors conduct its testing and just do not understand the goal of software metrological testing or more correctly verification. Meanwhile, there exists the particular difference between software testing and metrological verification, noticed by the authors.

Software testing is the process of technical study designed to identify information about software quality relative to the context in which it is used. The testing technique includes both a process for finding errors or other bugs, and examinations of software components for the purpose of a specific assessment, such as:

- compliance with the requirements of designers and developers;

- correct answer for all possible inputs;
- performance of functions at an acceptable time;
- practicality;
- compatibility with current software and operating systems;
- compliance with customer's tasks, etc.

Software testing provides objective, independent information about software quality, risks, failures, refuses, etc. [5]. As can be seen from the above list of tasks performed through testing, none of them provides a quantitative assessment of the results of calculations conducted using the software, but only provides a qualitative assessment.

Metrological verification of software is significantly different from testing. And the main difference lies in the fact, that it first of all gives a quantitative estimate, namely, allows determining the error of the software. Software, conditionally, is the separate block of MI and participates in the calculation of the measurement result. This approach allows to apply metrological principles in relation to software, substantially improve, simplify and accelerate the process of metrological verification of modern MI, and also to unify the MV of MI software.

Fourth, the cyber-physical systems (CPS) are emerging on the market for production and services [6-8], the main elements of which are practically ready for use. And if not today, in the near future such systems will become the main production units of the world economy, which, depending on the task, will form a robotic complex with the corresponding software. And here are two questions. What software should use CPS so that they can perform different tasks? And by what criterion CPS should choose the software, including, for the involved MI? On the above questions, we will try to answer in the following article.

2. PURPOSE OF WORK

The goal of this issue is an acquaintance of the scientific world with the main tendencies in the development of metrology of modern measuring instrument and justification of the need for metrological verification of measuring instruments software.

3. KEY MOMENTS IN THE DEVELOPMENT OF MEASURING TECHNOLOGY AND METROLOGY

First, let's make a brief excursion in the near past of measuring technology. Note the key occasions that will help to understand the issues of the MV of MI software, that for today hung up in the indefinite state and one way or another must be resolved.

In the 19th century, as a result of researches in the electric phenomena, the first galvanometers appeared devices for measuring of direct and variable current. This time physicists from around the world were beginning to develop new methods of electrical measurements: Lenz has suggested a ballistic method, Christie suggested the bridge method, and Poggendorff suggested the compensation method. At the end of the 19th century two scientists D'Arsonval and Deprez have created the first high-sensitivity galvanometer. In a few years a physicist Dolivo-Dobrovolsky developed devices which later became the basis for modern voltmeters, ammeters and wattmeters. It should be noted that in the first steps of the development of electrical MI, no one paid special attention to the need for MV of developed MI, in the context as we understand it for today. However, in parallel, there were developed standard instruments and exemplary measures that provided reproduction, storage and transmission of the unit of physical size, and later were used as means of metrological verification.

At that time MI were mainly used in scientific researches. However, rapid development of the creation and production of new materials and complex products that needed a certain technological process, led to the fact that MI began to be widely used in production. The quality of the manufactured products depended on the accuracy of maintaining certain technological parameters such as temperature, pressure etc., which were measured by MI. Therefore, the accuracy of the measurement of physical quantities clearly influenced the quality of production. Therefore, the MV of MI was necessary, which allowed ensuring the proper condition of measuring technique.

Let us consider most common analog MI. Block diagram of MV of such MI is presented in figure 1.

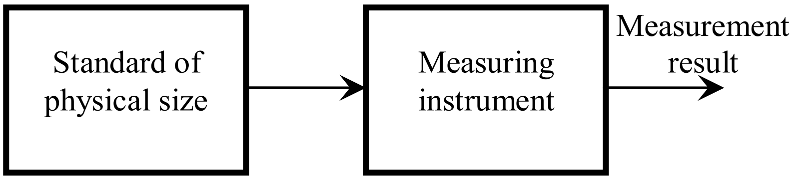

Fig. 1. Block diagram of metrological verification of analog measuring instrument

The known physical quantity is given to the MI input. A measurement result is obtained at the output. When the measurement error is derived, it becomes possible to compare its value with the value of MI class. Then we receive possibility to conclude about the suitability or unsuitability of the MI for the certain application.

Development of electrical MI element base including the transistors, amplifiers, specialized microcircuits and more, and the simplification of electrical MIs, lead to the emergence of a wide range of non-electrical MIs. Their distinguished features of design are the next:

- primary transducer, which converts the measured physical quantity into electrical one, mainly in current and voltage;
- MI of aforesaid electric value.

Here is arising up an interesting circumstance, which in the future would allow understand the necessity of MI software MV. What does it mean? Nothing hinders the MV of such MI according to the structural scheme presented in figure 1: for instance, primary transducers are checked in such a way. And electrical MI is checked by block diagram presented in figure 2.

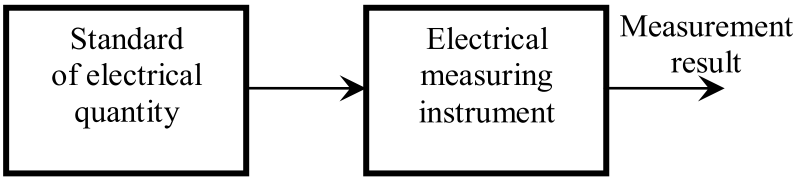

Fig. 2. Block diagram of metrological verification of electrical measuring instrument

Why the functional blocks of MIs have to be checked separately?

First, due to the fact that the standards of electric quantities, mainly, are inherent in lower uncertainties compare to the standards of non-electric quantities.

Second, the duration to verify non-electrical MI is longer than of electrical MI. For example, during MV, the transition from one voltage to another one takes the seconds, and the similar transition in temperature would takes from ten minutes to hour.

Third, the separation allows unify the process of MV of electrical MI: mainly the output signal of the primary transducers of non-electrical quantities is unified, f.i., 0-10 V, 0-20 mA. So, for convenience and for speedy MV, functional blocks of such MI are checked separately.

The last step for today in the development of measuring technique has been fulfilled with the dissemination of microcontrollers. What has essentially changed with the emergence of these two elements of digital technique? This allowed to move practically all mathematical processing of the measurement results from the analog part to the digital and significantly simplifies the analog part and, as a consequence, reduce the errors of MI. This can be clearly demonstrated on the example of measuring the rms voltage, which is determined by the formula:

$$U_{skz} = \sqrt{\frac{1}{T}\int_0^T u(t)^2\,dt}\,. \tag{1}$$

Block diagram of analog MI of the rms voltage is presented in figure 3.

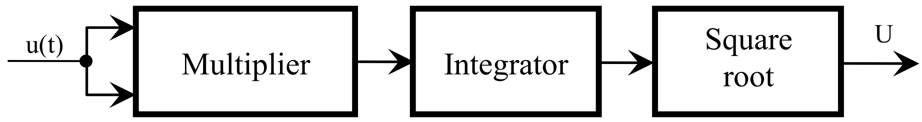

Fig. 3. Block diagram of analog measuring instrument of the rms voltage

To find the rms voltage U_{skz} is necessary to bring the input signal *u(t)* to the square using analog multiplier, integrate and take the square root. The error of such transformation is at best 0.5 – 1 %.
The use of microcontrollers allowed calculating the rms voltage in digital form by the formula:

$$U_{skz} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} u_i^2}\,. \tag{2}$$

Block diagram of digital MI of the rms voltage is presented in figure 4.

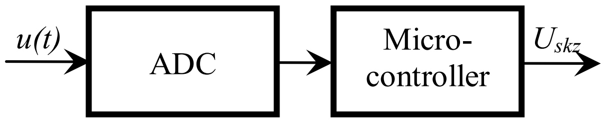

Fig. 4. Block diagram of digital measuring instrument of the rms voltage

Due to such changes in the structure of the MI succeeded in significantly reducing the measurement error. Comparing figure 3 and figure 4, it is possible to draw conclusion that the main data processing and obtaining the result of measurement occurs in the microcontroller software. And here is another metrological curiosity. In our case, almost 100% of mathematical processing digital data obtained with the use of ADC, and the calculation of the measurement result is carried out using software. In spite of this, the metrological characteristics of the ADC are normalized, and the software remains in the metrological sense incognito and conceals your metrological characteristics.

4. METROLOGICAL VERIFICATION OF MODERN MEASURING INSTRUMENTS

More than once during the discussions presented in this article sounded assertion: the device is checked in general, and there is not a necessity to check the software separately. But is it so? Do we properly check modern MI? To answer this question, we give a small example carried out by the authors of article and provide some explanations.

Verification of classic MI (and, unfortunately, modern also) mainly implemented in a few points from the range of MI. Such a small number of verification points are mostly sufficient, since the dependence of the error on the measured value has a monotone character, for example, is monotonically increasing or monotonically decreasing. And this, in our opinion, was correct only until such time as the main mathematical processing and calculation of the measurement result began to be conducted with using the software. What does it mean?

Figure 5 shows the dependence of relative error δ_{fs} of amplitude calculation of spectral harmonics by the function fft () from signal frequency for data of type double (floating point numbers) and data of type int (integer numbers, which answer to 16-bit ADC).

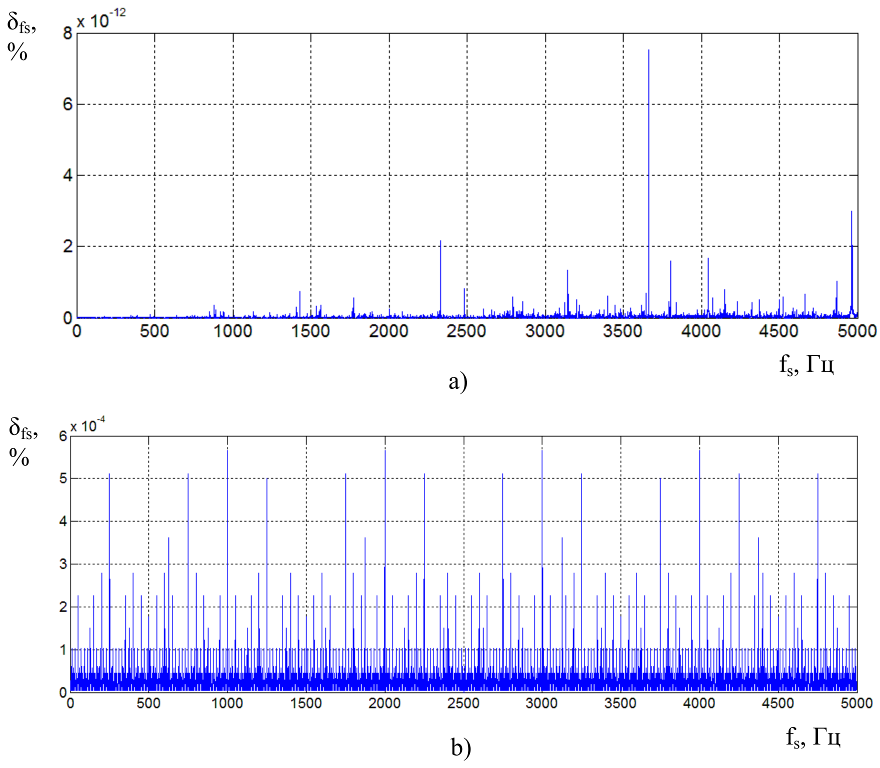

Fig. 5. Dependence of relative error δ_{fs} of amplitude calculation of spectral harmonics by the function fft () from signal frequency for: a) data of type double, b) data of type int, which answer to 16-bit ADC

As can be seen from figure 5, the relative error of the amplitude calculation of spectral harmonics has pseudo-random character. There is no clearly expressed monotonically increasing or monotonically decreasing dependence. In such case, taking only a few points for verification of MI, whose software makes the function fft(), it is possible to get the improper results of MV. The probability that we get the maximum error of the function fft () is sufficiently small. Therefore, the verification of such MI must be done at all points of the range of the measured value, in this case by frequency. Certainly, such verification on the structural scheme of MV (figure 1) will be sufficiently long. And there is not necessity to check the analog part at every point in the range of the measured value, since the above errors relate only to the software that is used to calculate the values of spectral harmonics. And so this suggests that it is necessary to conduct MV of software separately. This will allow us to make a quickly verification in autonomy mode for each measured value and define the maximal error of measuring result, which is determined using the software.

Another argument against the MV, which is put forward by specialists of digital technique is that, taking into account modern possibilities, they can provide practically any computational error (within reasonable limits). This can be achieved by increasing the data bus of microcontrollers and microprocessors. And this is certainly true. However, the specialists of measurements are always limited by the ADC bit depth. And regardless of size the data bus of the microcontroller or microprocessor, the determining influence on the calculation error of measurement result with software will have the ADC bit depth. And the influence of bit on the calculation error of measuring result is quite large.

According to the results of the research (figure 5), the transition from the data type double (floating-point numbers) to the data type int (integers) taking into account the size of the ADC (in our case, 16 bit) leads to a significant increase in the error of amplitude calculation of spectral harmonics by the function fft(). For data type double, the maximum relative error of the function fft () is $7.5 \cdot 10^{-12}\%$ (figure 5a), and for data type int it is $5.7 \cdot 10^{-4}\%$ (figure 5, b). Thus, the error increases by almost 8 orders of magnitude.

Therefore for the quantitative estimation of error of MI software, that predefined by limit nature of ADCs bit, it is expedient to conduct MV of MI software using digital data standards. And every software would have to get some metrological characteristics, which in some way connected with the metrological characteristics of the ADC.

5. METROLOGICAL VERIFICATION OF SOFTWARE DURING THE EXPLOITATION

Another debatable question is a necessity of MV of MI software on the stage of exploitation. Since the software for MI does not change during exploitation, then his verification should be done only at the design and development stage.

However, today the theoretical and practical foundations of CPS are being created (except for emergencies). Depending on the put task CPS will form an original robotic computer system. For this purpose, components of the CPS and related software of general purpose and software that will be used for MI of robotic equipment will be involved from the existing park. In order for CPS to perform varied tasks, they must use flexible software, which will mainly be obtained through cloud-based technologies. That is, with the statement of the new task will be used other MI software. And it suggests an idea that in such case software, which will be calculate the result of the measurement using a certain algorithm, must undergo MV. This will guarantee the correct work of the robots involved in the CPS, and thus will ensure the safety of human life.

In addition there is another question: after what criterions the CPS choose software, and also for the involved MI. Which software parameter should characterize it so that the CPS correctly chooses the software that is optimal for the task. And there is a simple answer on this question: for MI software, which is used in the CPS, such characteristic is error of software computing the measurement result. That is, the software will be characterized by not qualitative, but a quantitative characteristic, which enables quickly to compare variants of the same type software and choose the optimal, in obedience to the put task of measurement.

Certainly, the producers of MI software must conduct MV and ascribe declared metrological characteristics of software. On the other hand, the CPS must conduct a MV of software and check whether the received metrological characteristics are in accordance with the declared. If the result is positive, then the software can be used. Otherwise, another software is searched.

6. CONCLUSIONS

Recently considering in science, the MV of MI software is used extremely rarely. In the nearest future, due to implementation of CPS in production and services, the issue of MV of MI software will need to be resolved and regulated by law.

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